Simulations of Atmospheric Flows in the Boundary Layer Over Inhomogeneous Surface Conditions

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LONG TERM GOALS

The goal of this project is to improve the description and prediction of resolvable and subgrid-scale atmospheric fields over inhomogeneous surfaces and to develop an integrated modeling system for weather phenomena and dispersion effects on a variety of spatial and temporal scales.

OBJECTIVES

Specific objectives include: 1) developing a fully-compressible and computationally efficient model that can be applied to atmospheric and dispersion fields on domains ranging from microscale to mesoscale, 2) investigating turbulence transfer within the atmospheric boundary layer, 3) formulating a conceptual model of nonlocal turbulent mixing, and 4) developing a method of evaluating atmospheric models. This work is supported by the Office of Naval Research, Marine Meteorology and Atmospheric Effects.

APPROACH

We have developed and used a fully-compressible, 2-D atmospheric model with a high-resolution Monte Carlo radiation scheme to simulate a case of strong convection, as well as the effects of broken cloudiness on modification of a radiation field (Kora• in et al. 1998a). Basic results from this study have initiated a series of LES experiments using the code developed by Moeng (1984) and modified by Andren (1995). For a purpose of visualizing atmospheric flows and applying model results to dispersion processes over inhomogeneous surfaces, we have developed a Lagrangian random particle (LAP) model (Kora• in et al. 1998b). Further application of the modeling results to tracer measurements prompted the creation of a unique method -- "Tracer Potential" -- to evaluate atmospheric models (Kora• in et al. 1998f, 1998g, 1998c, and 1998d). Numerical experiments using the cloud-resolving and LES models have led to the development of a novel turbulence parameterization and treatment of nonlocal mixing. Preliminary results are shown in Kora• in et al. (1998e).

WORK COMPLETED

Numerical simulations of the buoyant bubble in a neutral environment as well as the structure of a radiation field in broken clouds were completed using the cloud-resolving model (Kora• in et al. 1998a). Algorithms for a new turbulence parameterization and nonlocal mixing were developed and tested (Kora• in et al. 1998e). Simulations using the 3-D LES code have recently been performed which focused on a case of strong convection, destruction of the buoyant bubble, and turbulence structure within the inhomogeneous atmospheric boundary layer.

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The "Tracer Potential" method of evaluating atmospheric models has been applied to tracer field data from a program conducted in the southwest U.S. (Kora• in et al. 1998f, 1998g, 1998c, 1998d). The developed LAP model was tested against the tracer data and the results were reported by Kora• in et al. (1998b) and Isakov (1998).

RESULTS

According to a comparison with aircraft-measured radiative fluxes, the Monte Carlo scheme has an accuracy of 5%, which corresponds to the uncertainty in predicted heating rate. The most critical parameter in shortwave flux calculation was found to be cloud optical thickness. Sensitivity tests revealed that for small changes in optical thickness (e.g., 0.2), the net flux changed up to 30%. A change in cloud optical thickness from 0.8 to 4 caused a flux variation of an order of magnitude. Due to the complex geometry of broken cloud elements, the normalized downward shortwave flux can be increased or reduced depending on the zenith angle.

Figure 1 shows a top view of atmospheric pollutants as simulated with the same dispersion model (LAP), but with wind fields obtained from different atmospheric models. Quantification of this differences was estimated by the "Tracer Potential" method.

The LAP model reproduced the main features of measured tracer concentrations in complex terrain at distances from the source ranging from 20 to 300 km, including channeling of the transported tracers. We tested prognostic (MM5) and diagnostic (CALMET) atmospheric models as input to the same dispersion model (LAP). We used tracer data for nine days in summer 1992 to evaluate atmospheric and dispersion models. Predicted tracer concentrations show quite good agreement with measurements at eleven available receptors, with correlation coefficients of 0.49 (LAP with MM5) and 0.39 (LAP with CALMET).

According to the preliminary results of the method for determining nonlocal turbulent transfer, nonlocal mixing contributed approximately 10% to the evolution of the boundary layer as compared to local mixing in the stratocumulus case. The contribution increased to approximately 30-40% in the convective test case.

Three LES initial tests were recently conducted. The first test focused on evolution of the turbulence transfer under highly convective conditions (Fig. 2). A drop of 10 K/km was set up as an initial profile for the potential temperature. Analysis of the resulting turbulence structure is in progress. Figure 3 shows the transition time of the turbulence kinetic energy in reaching the quasi-equilibrium state.

The second test focused on the deformation and destruction of the positively buoyant bubble in a neutral environment and the associated generation of turbulence fields over homogeneous surfaces. Figure 4 shows an isosurface of the potential temperature at five minutes after the bubble was initiated. This case will be a control run for the next LES experiment with the bubble destruction over the inhomogeneous surface heat flux. Currently, we are setting up a case of an inhomogeneous boundary layer with larger stability in the upper part and instability due to surface heat and momentum fluxes in the lower part of the boundary layer.

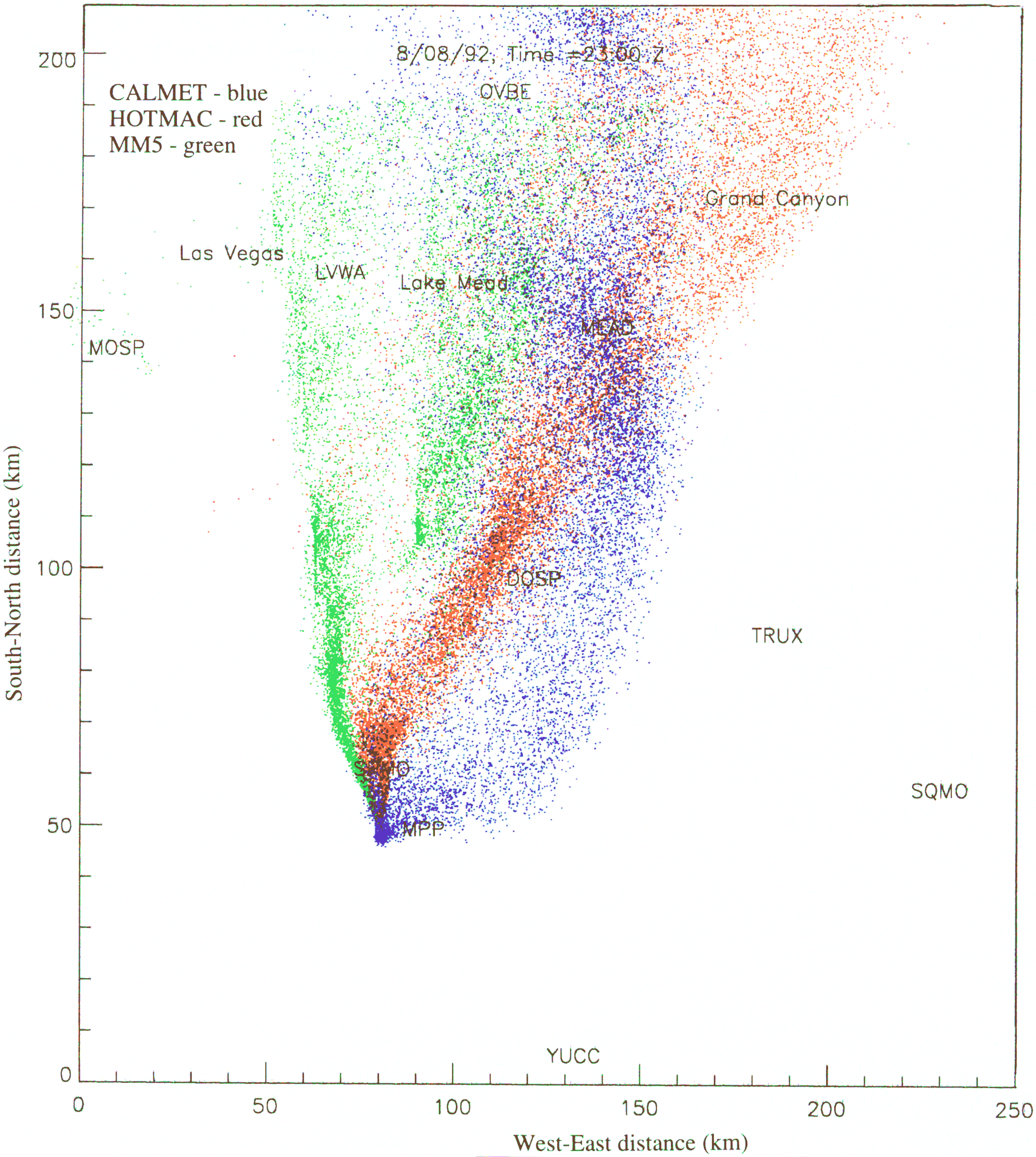

Figure 1: Horizontal projection of the plume as simulated by the LAP model with different meteorological inputs: CALMET (blue), HOTMAC (red) and MM5 (green).

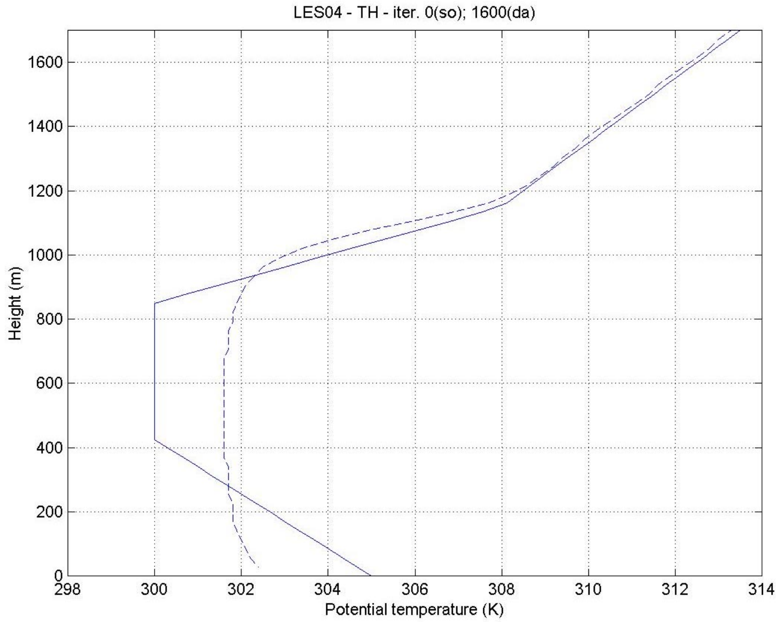

__Figure 2: Evolution of the potential temperature profile as simulated by the LES code.__

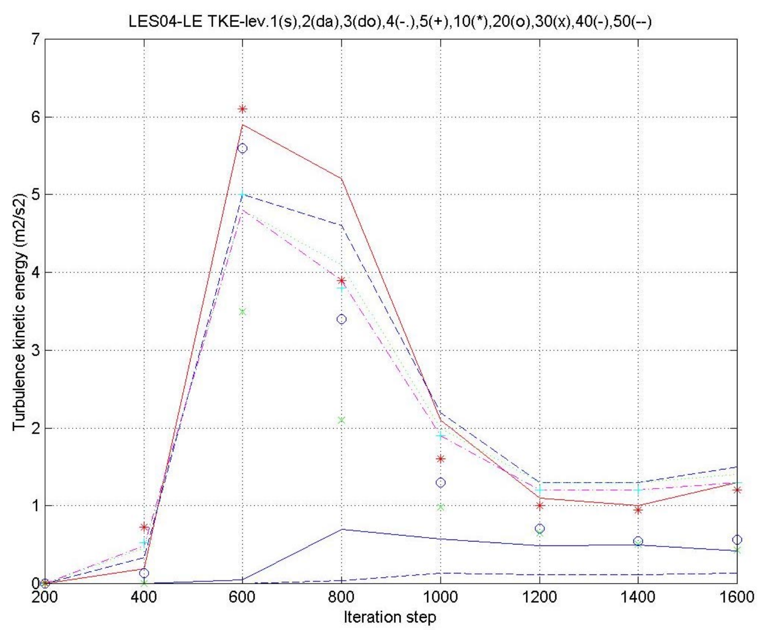

__Figure 3: Time series of the turbulence kinetic energy at certain vertical levels as simulated by the LES code.__

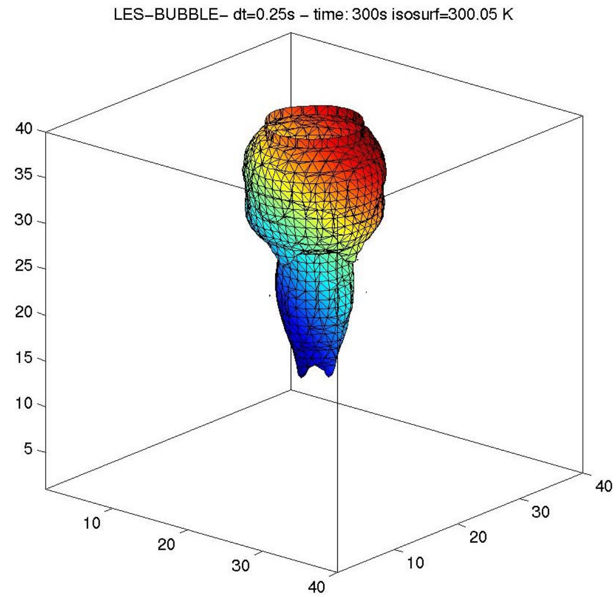

Figure 4: Isosurface of potential temperature equal to 300.05 K after five minutes during the LES run. The bubble was initially spherical and warmer by 5 K (in the center) than the neutral environment (300 K).

IMPACT

The models and methods we have developed will both increase understanding of and lead to improved prediction of the atmospheric boundary layer, particularly in the areas of turbulence transfer and atmospheric transport and dispersion. This has an obvious application to naval and aircraft operations as well as to defense against chemical or biological weapons. Most of the models can be operated on a PC platform, permitting use by tactical military units.

TRANSITIONS

A research team from Flinders University in Australia is testing and analyzing radiation fields of broken clouds simulated by the Monte Carlo method. A team from the University of Uppsala in Sweden (Dr. Michael Tjernström) plans to use our method of nonlocal mixing in a collaborative study of the ASTEX data, as well as to analyze the cloud-resolving and LES results. Dr. Leif Enger from the same institution is developing a method of evaluating dispersion models based on our "Tracer Potential" method of evaluating atmospheric models. Drs. Michael Tjernström and Leif Enger will also use our LAP model for coastal and complex terrain, respectively. Dr. Steve Chai (DRI) obtained the code for our cloud-resolving model and is currently adding a microphysical parameterization. A significant collaboration has been initiated with Dr. Marek Uliasz (CSU-ASTER) on inter-comparing our LES results with the RAMS-LES and developing further experiments in turbulence evolution over inhomogeneous surfaces and within inhomogeneous boundary layers.

An essential collaboration has been established with Dr. Anders Andrén (formerly of the University of Uppsala in Sweden) in designing, executing, and analyzing the LES experiments.

RELATED PROJECTS

Work on this project benefitted from work on and results from another ONR-funded project (N00014-96-1-0980) which focused on simulations of coastal dynamics. Darko Kora• in is also a P.I. on this project. Performance has been enhanced by collaboration with Dr. Luis Mendez of the University of California, Davis, Dr. Michael Tjernström of the University of Uppsala, Sweden, and Dr. Marek Uliasz (CSU-ASTER). Research conducted in this project has led to a proposal funded by DOD-ONR (Drs. Steve Chai and Darko Kora• in) focusing on modeling the dispersion of vapor and aerosol particulates in complex terrain. The "Tracer Potential" method and the LAP model were also used in several EPA-related projects and the NOAA-funded weather modification program (see website).

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